PHILOSOPHICAL

TRANSACTIONS.

XIX. *An Attempt to make a Thermometer for meaſuring the higher Degrees of Heat, from a red Heat up to the ſtrongeſt that Veſſels made of Clay can ſupport. By* Joſiah Wedgwood; *communicated by Sir* Joſeph Banks, *Bart. P. R. S.*

Read May 9, 1782.

A MEASURE for the higher degrees of heat, ſuch as the common thermometers afford for the lower ones, would be an important acquiſition, both to the philoſopher and the practical artiſt. The latter muſt feel the want of ſuch a meaſure on many occaſions; particularly when he attempts to follow, or apply to uſe, the curious experiments of Mr. POTT, related in his Lithogeognoſia, and other modern writers upon ſimilar ſubjects. When we are told, for inſtance, that ſuch and ſuch materials were changed by fire into a fine white, yellow, green, or other coloured glaſs: and find, that theſe effects do not happen, unleſs a particular degree of fire has fortunately been hit upon, which degree we cannot be ſure of ſucceeding in again:—when we are diſappointed, by having the reſult at ſome times an unvitrified maſs, and at others an over-vitrified ſcoria, from a little deficiency or exceſs of heat:—when we ſee colours altered, not only in ſhade but in kind, and in many caſes deſtroyed, by a ſmall augmentation of the heat which had produced them; inſomuch, that in the gradual increaſe of the fire, a preciſe moment of time muſt be happily ſeized, in order to catch them in perfection:—and when inconveniences, ſimilar to theſe, ariſe in operations by fire upon metals and other ſubſtances:—how much is it to be wiſhed, that the authors had been able to convey to us a meaſure of the heat made uſe of in their valuable proceſſes!

In a long courſe of experiments, for the improvement of the manufacture I am engaged in, ſome of my greateſt difficulties and perplexities have ariſen from not being able to aſcertain the heat to which the experiment-pieces had been expoſed. A *red, bright red*, and *white heat*, are indeterminate expreſſions; and even though the three ſtages were ſufficiently diſtinct from each other, they are of too great latitude; as the brightneſs or luminouſneſs of fire increaſes, with its force, through numerous gradations, which can neither be expreſſed in words, nor diſcriminated by the eye. Having no other reſource, I have been obliged to content myſelf with ſuch meaſures as my own kilns and the different parts of them afforded. Thus the kiln in which our glazed ware is fired furniſhes three meaſures, the bottom being of one heat, the middle of a greater, and the top ſtill greater: the kiln in which the biſcuit ware is fired furniſhes three or four others, of higher degrees of heat; and by theſe I have marked my regiſtered experiments. But though theſe meaſures had been fully adequate to my own views, which they were not, it is plain, that they could not be communicated to others; that their uſe is confined to a particular ſtructure of furnaces, and mode of firing; and that, upon any alteration in theſe, they would become uſeleſs and unintelligible, even where now they are beſt known. And, indeed, as this part of the operation is performed by workmen of the loweſt claſs, we cannot depend upon any great accuracy even in one and the ſame furnace. It has accordingly often happened, that the pieces fired in the top of the kiln in one experiment have been made no hotter than thoſe fired in the middle in another, and *vice verſâ*.

The force of fire, in its higher as well as lower ſtages, can no otherwiſe be juſtly aſcertained than by its effects upon ſome known body. Its effect in changing colours has already been hinted at; and I have obſerved compoſitions of calces of iron with clay to aſſume, from different degrees of fire, ſuch a number of diſtinct colours and ſhades as promiſed to afford uſeful criteria of the reſpective degrees.

With this idea, I prepared a quantity of ſuch a compoſition, and formed it into circular pieces, about an inch in diameter, and a quarter of an inch thick. A number of theſe was placed in a kiln, in which the fire was gradually augmented, with as much uniformity and regularity as poſſible, for near ſixty hours. The pieces, taken out at equal intervals of time during this ſucceſſive increaſe of heat, and piled in their order upon one another in a glaſs tube, exhibited a regular and pretty extenſive ſeries of colours; from a fleſh-colour to a deep browniſh-red, from thence to a chocolate, and ſo on to nearly black, with all the intermediate tints between theſe colours. A back being fixed to the tube, like the ſcale of a thermometer, and the numbers of the pieces marked upon it reſpectively oppoſite to them, it is obvious, that theſe numbers may be conſidered as ſo many thermometric diviſions or degrees; and that, if another piece of the ſame compoſition be fired in any other kiln or furnace, not exceeding the utmoſt heat of the firſt, it will acquire a colour correſponding to ſome of the pieces in the tube, and thus point out the degree of heat which that piece, and conſequently ſuch other matters as were in the fire along with it, have undergone.

It muſt however be confeſſed, that, for general uſe, a thermometer on this principle is liable to objection, as ideas of colours are not perfectly communicable by words; nor are all eyes, or all lights, equally adapted for diſtinguiſhing them, eſpecially the ſhades which approach near to one another; and the effects of phlogiſtic vapours, in altering the colour, may not in all caſes be eaſily guarded againſt.

In conſidering this ſubject attentively, another property of argillaceous bodies occurred to me; a property which obtains, in a greater or leſs degree, in every kind of them that has come under my examination, ſo that it may be deemed a diſtinguiſhing character of this order of earths: I mean, the *diminution of their bulk by fire*; I have the ſatisfaction to find, in a courſe of experiments lately made with this view, that it is a more accurate and extenſive meaſure of heat than the different ſhades of colour.

I have found, that this diminution begins to take place in a low red-heat; and that it proceeds regularly, as the heat increaſes, till the clay becomes vitrified, and conſequently to the utmoſt degree that crucibles, or other veſſels made of this material, can ſupport. The total contraction of ſome good clays which I have examined, in the ſtrongeſt of my own fires, is conſiderably more than one-fourth part in every dimenſion.

If, therefore, we can procure at all times a clay ſufficiently apyrous or unvitreſcible, and always of the ſame quality in regard to contraction by heat; and if we can find means of meaſuring this contraction with eaſe and minute accuracy, I flatter myſelf, that we ſhall be furniſhed with a meaſure of fire ſufficient for every purpoſe of experiment or buſineſs.

We have, in different parts of England, immenſe beds of clay; each of which, at equal depths, is pretty uniform in quality throughout its whole extent. Of all the ſorts I have hitherto tried, ſome of the pureſt Corniſh porcelain clays ſeem the beſt adapted, both for ſupporting the intenſity, and meaſuring the degrees, of fire.

For preparing and applying this material to thermometric purpoſes the following method is propoſed.

The clay is firſt to be waſhed over, and, whilſt in a dilute ſtate, paſſed through a fine lawn. Let it then be made dry, and put up in boxes *,

---

* While the clay is thus kept dry in boxes, as well as while it continues in its natural bed, it is ſecure from alterations in quality, which clays in general are ſubject to undergo, when expoſed, for a long courſe of years, to the joint actions of air and moiſture.—In the lawns I made uſe of, the interſtices were each leſs than the 100,000 part of an inch.

The dry clay is to be ſoftened, for uſe, with about two fifths of its weight of water; and formed into ſmall pieces, in little moulds of metal, ſix-tenths of an inch in breadth, with the ſides pretty exactly parallel, this being the dimenſion intended to be meaſured, about four-tenths of an inch deep, and one inch long. To make the clay deliver eaſily, it will be neceſſary to oil the mould, and make it warm.

Theſe pieces, when perfectly dry, are put into another iron mould or gage, conſiſting only of a bottom, with two ſides, five-tenths of an inch deep; to the dimenſions of which ſides the breadth of the pieces is to be pared down.

For meaſuring the diminution which they are to ſuffer from the action of fire, another gage is made, of two pieces of braſs, twenty-four inches long, with the ſides exactly ſtraight, divided into inches and tenths, fixed five tenths of an inch aſunder at one end, and three-tenths at the other, upon a braſs plate; ſo that one of the thermometric pieces, when pared down in the iron gage, will juſt fit to the wider end. Let us ſuppoſe this piece to have diminiſhed in the fire one-fifth of its bulk, it will then paſs on to half the length of the gage; if diminiſhed two-fifths, it will go on to the narroweſt end; and in any intermediate degree of contraction, if the piece be ſlid along till it reſts againſt the converging ſides, the degree at which it ſtops will be the meaſure of its contraction, and conſequently of the degree of heat it has undergone.

Theſe are the outlines of what appears to me neceſſary for the making and uſing of this thermometer; and it is hoped, that the whole proceſs will be found ſufficiently ſimple, and eaſy of execution. It may, nevertheleſs, be proper to take notice of a few minuter circumſtances, and to mention ſome obſervations which occurred in the progreſs of the inquiry.

I. There ought to be a certainty of the clay being eaſily, and at all times, procurable in ſufficient quantity, and on moderate terms. That this is the caſe with the clay here made choice of, will be evident to every one acquainted with the natural hiſtory of Cornwall, where there are beds of this clay, inexhauſtible, and in too many hands to be monopolized. If this ſhould not prove ſatisfactory, the author offers to this illuſtrious Society, and will think himſelf honoured by their acceptance of, a ſufficient ſpace in a bed of this clay to ſupply the world with thermometer-pieces for numerous ages; and he does not apprehend, that any greater inconveniences can ariſe to foreign artiſts or philoſophers, from their being ſupplied with clay for theſe thermometers from this ſpot only, than what we now feel from being ſupplied with mercury for the common thermometers from the Spaniſh or Hungarian mines.

II. We ought to be aſſured alſo, that all the clay made uſe of for theſe thermometers is perfectly ſimilar. For this purpoſe, it will be beſt to dig it out of the earth in conſiderable quantity at once, an extent of ſome ſquare feet or yards in area, and to the depth of ſix or ſeven yards or more from the ſurface, and to mix the whole thoroughly together, previous to the further preparation already mentioned. When the firſt quantity is exhauſted, another perpendicular column may be dug from the ſame bed, cloſe to the firſt, to the ſame depth, and prepared in the ſame manner; by which means we may be aſſured of its ſimilarity with the former parcel, and that it will diminiſh equally in the fire.

III. This clay, dried by the ſummer heat, or in a moderately warm room, or with more heat before a fire, has not been obſerved to differ in *degree* of dryneſs. After being ſo dried, it loſes about a hundredth part of its weight in the heat of boiling water, about as much more in that of melted lead, and from thence to a red-heat ten parts, in all $\frac{12}{100}$. Each of theſe heats ſoon expels from the clay its determinate quantity of matter, chiefly air; after which, the ſame heat, though continued for many hours, has no further effect. I had ſome hopes, that the graduation of the common thermometer might be continued, upon this principle, up to the red-heat at which the ſhrinking of the clay commences, ſo as to connect the two thermometers together by one ſeries of numbers; but the loſs of weight appears not to be ſufficiently uniform or proportional to the degree of heat to anſwer that purpoſe; for it was found to go on quicker, and bladders tied to the mouths of the veſſels in which the pieces were heated, became more rapidly diſtended, at the commencement of redneſs than at any other time. From low red-heat to a ſtrong one, ſuch as copper melts in, the loſs of weight was only about two parts in a hundred; though the difference between theſe two heats appears to be much greater than what the ſame loſs correſponds to in the lower ſtages. After this period, the decreaſe of weight intirely ceaſed.

The vapours expelled from the clay, caught ſeparately in the different degrees of heat, ſeemed, from the few trials made with them, to conſiſt of common air mixed with fixt air. They all precipitated lime-water; that which was firſt extricated, exceeding weakly; the others more and more conſiderably; but the laſt not near ſo ſtrongly as the air expelled from lime-ſtone in burning. None of them were inflammable.

IV. The thermometric pieces may be formed much more expeditiouſly than in the ſingle mould, by means of an inſtrument uſed for ſimilar purpoſes by the potters. It conſiſts of a cylindrical iron veſſel, with holes, in the bottom, of the form and dimenſions required. The ſoft clay, put in the veſſel, is forced by a preſs down through theſe apertures, in long rods, which may be cut while moiſt, or broken when dry, into pieces of convenient lengths. It was hoped, that this method would of itſelf have been ſufficient, without the addition of the paring gage, making proper allowance, in the ſize of the holes, for the ſhrinking of the clay in drying. But it was found, that a variety of little accidents might happen to alter the ſhape and dimenſions of the pieces, in a ſenſible degree, while in their ſoft ſtate; ſo that it will be always ſafeſt to have recourſe to the paring gage, for aſcertaining and adjuſting their breadth when perfectly dry, this being the period at which the pieces are exactly alike with regard to their future diminiſhing; ſo that if they are now reduced to the ſame breadth, we may be ſure that they will ſuffer equal contractions from equal degrees of heat afterwards, whether they have been made in a mould, or by a preſs, or in any other way; neither is any variation in the length or thickneſs of theſe pieces of the leaſt conſequence, provided one of the dimenſions, that by which they are afterwards to be meaſured, is made accurate to the gage.

V. It will be proper to bake the pieces, when dry, with a low red-heat, in order to give them ſome firmneſs or hardneſs, that they may, if neceſſary, be able to bear package and carriage; but more eſpecially to prepare them for being put into an immediate heat, along with the matters they are to ſerve as meaſures to, without burſting or flying, as unburnt clay would do. We need not be ſolicitous about the preciſe degree of heat employed in this baking, provided only that it does not exceed the loweſt degree which we ſhall want to meaſure in practice; for a piece that has ſuffered any inferior degrees of heat, anſwers as well for meaſuring higher ones as a piece which has never been expoſed to fire at all. In this part of the preparation of the pieces, it may be proper to inform the operator of a circumſtance, which, though otherwiſe immaterial, might at firſt diſconcert him: if the heat is not in all of them exactly equal, he will probably find, that while ſome have begun to ſhrink, others are rather enlarged in their bulk; for they all ſwell a little juſt on the approach of redneſs. As this is the period of the moſt rapid produce of air, the extenſion may perhaps be owing to the air having at this moment become elaſtic to ſuch a degree, as to force the particles of the clay a little aſunder before it obtains its own enlargement.

VI. Each diviſion of the ſcale, though ſo large as a tenth of an inch, anſwers to $\frac{1}{600}$th part of the breadth of the little piece of clay. We might go to much greater nicety, either by making the diviſions ſmaller, or the ſcale longer; but it is not apprehended, that any thing of this kind will be found neceſſary: and, indeed, in proceeding much further in either way, we may poſſibly meet with inconveniences ſufficient to counterbalance the apparent additional accuracy of meaſurement.

VII. The diviſions of this ſcale, like thoſe of the common thermometers, are unavoidably arbitrary; but the method here propoſed appears ſufficiently commodious and eaſy of execution, the diviſions being adjuſted by meaſures everywhere known, and at all times obtainable: for however the inches uſed in different countries may differ in length, this cannot affect the accuracy of the ſcale, provided that the proportions between the wider and narrower end of the gage are exactly as five-tenths of thoſe inches to three-tenths, and the length 240 of the ſame tenths; and that the pieces in their perfectly dry ſtate, before firing, fit preciſely to the wider end. When one gage is accurately adjuſted to theſe proportional meaſures, two pieces of braſs ſhould be made, one fitting exactly into one end, and the other into the other: theſe will ſerve as ſtandards for the ready adjuſtment of other gages to the dimenſions of the original.

By this ſimple method we may be aſſured, that thermometers on this principle, though made by different perſons, and in different countries, will all be equally affected by equal degrees of heat, and all ſpeak the ſame language: the utility of this laſt circumſtance is now too well known to need being inſiſted on.

VIII. If a ſcale two feet in length ſhould be reckoned inconvenient, it may be divided into two, of one foot each, by having three pieces of braſs fixed upon the ſame plate; the firſt and ſecond, five-tenths of an inch apart at one end, and four-tenths at the other; the ſecond and third, four-tenths at one end, and three-tenths at the other; ſo that the firſt reaches to the 120th diviſion, and the ſecond from thence to the 240th.

IX. As this thermometer, like all others, can expreſs only the heat felt by itſelf, the operator muſt be careful to expoſe the pieces to an equal action of the fire with the body whoſe heat he wants to meaſure by them. In kilns, ovens, reverberatories, under a muffle, and wherever the heat is pretty ſteady and uniform, the means of doing this are too obvious to need being mentioned. But in a naked fire, where the heat is neceſſarily more fluctuating, and unequal in different parts of the fuel, ſome precaution will be required.

The thermometer-piece may generally be put into the crucible, along with the ſubject-matter of the experiment. But where the matter is of ſuch a kind as to melt and ſtick to it, the piece may be previouſly incloſed in a little caſe made of crucible clay. The ſmallneſs of the pieces will admit of this being done without inconvenience, at leaſt in any but the ſmalleſt crucibles, as the pieces themſelves may be diminiſhed to any ſize that may be found proper, provided only that one of the dimenſions, five-tenths of an inch, be preſerved, as mentioned in *Obſ.* 4.

For the very ſmalleſt ſort of crucibles, the caſe may be put in cloſe to the crucible, ſo as to form as it were an addition to its bulk on the outſide. If it be aſked, why the caſe is not always thus put in by the ſide of the crucible? it is anſwered, that in judging of the heat of *large* crucibles from a thermometer-piece placed on the outſide of them, we may ſometimes be deceived, as the piece in its little caſe has been found to heat ſooner than the matter in the larger veſſel; but in *ſmall* ones, as the crucible and caſe are nearly alike in bulk, there is little danger of error from this cauſe.

X. Theſe thermometer-pieces poſſeſs ſome ſingular properties, which we could not have expected to find united in any ſubſtance whatever, and which peculiarly fit them for the purpoſes they are here applied to.

1. When baked by only moderate degrees of fire, though they are, like other clays, of a porous texture, and imbibe

water; yet, when ſaturated with the water, their bulk continues exactly the ſame as in a dry ſtate.

2. By very ſtrong fire, they are changed to a porcelain or ſemi-vitreous texture; nevertheleſs, their contraction, on further augmentations of the heat, proceeds regularly as before, up to the higheſt degree of fire that I have been able to produce.

3. They bear ſudden alternatives of heat and cold; may be dropped at once into intenſe fire, and, when they have received its heat, may be plunged as ſuddenly into cold water, without the leaſt injury from either.

4. Even while ſaturated with water in their porous ſtate, they may be thrown immediately into a white heat, without burſting or ſuffering any injury.

5. Sudden cooling, which alters both the bulk and texture of moſt bodies, does not at all affect theſe, at leaſt not in any quality ſubſervient to their thermometric uſes.

6. Nor are they affected by long *continuance* in, but ſolely by, the *degree* of heat they are expoſed to. In three minutes or leſs, they are perfectly penetrated by the heat which acts upon them, ſo as to receive the full contraction which that degree of heat is capable of producing equally with thoſe which had undergone its action during a gradual increaſe of its force for many hours. Strong degrees of heat are communicated to them with more celerity than weak ones: perhaps the heat may be more readily tranſmitted, in proportion as the texture becomes more compact.

Theſe facts have been aſcertained by many experiments, the particulars of which are omitted, becauſe they would ſwell this paper much beyond the bulk intended.

XI. The uſe and accuracy of this thermometer for meaſuring, *after an operation*, the degree of heat which the matter has undergone, will be apparent. The foregoing properties afford means of meaſuring it alſo, eaſily and expeditiouſly, *during the operation*, ſo that we may know when the fire is increaſed to any degree previouſly determined upon. The piece may be taken out of the fire in any period of the proceſs, and dropped immediately into water, ſo as to be fit for meaſuring by the gage in a few ſeconds of time. At the ſame inſtant, another piece may be introduced into the place of the former, to be taken out and meaſured in its turn; and thus alternately, till the deſired degree of heat is obtained. But as the cold piece will be two or three minutes in receiving the full heat, and correſponding contraction; to avoid this loſs of time, it may be proper, on ſome occaſions, to have two or more pieces, according to convenience, put in together at firſt, that they may be ſucceſſively cooled in water, and the degrees of heat examined at ſhorter intervals. It will be unneceſſary to ſay any thing further upon precautions or procedures which the very idea of a thermometer muſt ſuggeſt, and in which it is not apprehended that any difficulty can occur, which every experimenter will not readily find means to obviate.

XII. It now only remains, that the language of this new thermometer be underſtood, and that it may be known what the heats meant by its degrees really are. For this purpoſe a great number of experiments has been made, from which the following reſults are ſelected.

The ſcale commences at a red-heat, fully viſible in daylight; and the greateſt heat that I have hitherto obtained in my experiments is 160°. This degree I have produced in an air-furnace about eight inches ſquare.

Mr. ALCHORNE has been ſo obliging as to try the neceſſary experiments with the pure metals at the Tower, to aſcertain at what degrees of this thermometer they go into fuſion; and it appears, that Swediſh copper melts at 27, ſilver at 28, and gold at 32.

Braſs is in fuſion at 21. Nevertheleſs, in the braſs and copper founderies, the workmen carry their fires to 140° and upwards: for what purpoſe they ſo far exceed the melting heat, or whether ſo great an additional heat be really neceſſary, I have not learnt.

The welding heat of iron is from 90 to 95; and the greateſt heat that could be produced in a common ſmith's forge 125.

Caſt iron was found to melt at 130°, both in a crucible in my own furnace, and at the foundery; but could not be brought into fuſion in the ſmith's forge, though that heat is only 5° lower. The heat by which iron is run down among the fuel for caſting is 150°.

As the welding ſtate of iron is a ſoftening or beginning fuſion of the ſurface, it has been generally thought that caſt iron would melt with much leſs heat than what is neceſſary for producing this effect upon the forged; whereas, on the contrary, caſt iron appears to require, for its fuſion, a heat exceeding the welding heat 35 or 40°, which is much more than the heat of melted copper exceeds the loweſt viſible redneſs.

Thus we find, that though the heat for melting copper is by ſome called a white heat, it is only 27° of this thermometer. The welding heat of iron, or 90°, is likewiſe a white heat; even 130°, at which caſt iron is in fuſion, is no more than a white heat; and ſo on to 160° and upwards is all a white heat ſtill. This ſhews abundantly how vague ſuch a denomination muſt be, and how inadequate to the purpoſe of giving us any clear ideas of the extent of what we have been accuſtomed to conſider as one of the three diviſions of heat in ignited bodies.

A Heſſian crucible, in the iron foundery, *viz.* about 150°, melted into a ſlag-like ſubſtance. Soft iron nails, in a Heſſian crucible in my own furnace, melted into one maſs with the bottom of the crucible, at 154°: the part of the crucible above the iron was little injured.

The *fonding* heat of the glaſs furnaces I examined, or that by which the perfect vitrification of the materials is produced, was at one of them 114° for flint-glaſs, and 124° for plate-glaſs; at another it was only 70° for the former, which ſhews the inequality of heat, perhaps unknown to the workmen themſelves, made uſe of for the ſame purpoſe. After complete vitrification, the heat is abated for ſome hours to 28 or 29°, which is called the *ſettling* heat; and this heat is ſufficient for keeping the glaſs in fuſion. The fire is afterwards increaſed, for working the glaſs, to what is called the *working* heat; and this I found, in plate-glaſs, to be 57°.

Delft ware is fired by a heat of 40 or 41°; cream-coloured, or Queen's ware, by 86°; and ſtone ware, called by the French *pots de grès*, by 102°: by this ſtrong heat, it is changed to a true porcelain texture. The thermometer-pieces begin to acquire a porcelain texture about 110°.

The above degrees of heat were aſcertained by thermometer-pieces fired along with the ware in the reſpective kilns. But this thermometer affords means of doing much more, and going further in theſe meaſures than I could at firſt even have expected; it will enable us to aſcertain the heats by which many of the porcelains and earthen wares of diſtant nations and different ages have been fired: for as burnt clay, and compoſitions in which clay is a prevailing ingredient, ſuffer no diminution of their bulk by being re-paſſed through degrees of heat which they have already undergone, but are diminiſhed by any additional heat (according to *Obſ.* V.), if a fragment of them be made to fit into any part of the gage, and then fired along with a thermometer-piece till it begins to diminiſh, the degree at which this happens points out the heat by which it had been fired before. Of ſeveral pieces of ancient Roman and Etruſcan wares, which I have examined, none appear to have undergone a greater heat than 32°, and none leſs than 20°; for they all began to diminiſh at thoſe or the intermediate degrees.

By means of this thermometer ſome intereſting properties of natural bodies may likewiſe be diſcovered or more accurately determined, and the genus of the bodies aſcertained. Jaſper, for inſtance, is found to diminiſh in the fire, like an artificial mixture of clay and ſiliceous matter; granite, on the contrary, has its bulk enlarged by fire, whilſt flint and quartzoſe ſtones are neither enlarged nor diminiſhed. Theſe experiments were made in fires between 70 and 80° of this thermometer. A ſufficient number of facts like theſe, compared with each other, and with the properties of ſuch natural or artificial bodies as we wiſh to find out the compoſition of, may lead to various diſcoveries, of which I have already found ſome promiſing appearances; but many more experiments are wanting to enable me to ſpeak with that certainty and preciſion on theſe ſubjects which they appear to deſerve.

A piece of an Etruſcan vaſe melted completely at 33°; pieces of ſome other vaſes and Roman ware about 36°; Worceſter china vitrified at 94°; Mr. SPRIMONT's Chelſea china at 105°; the Derby at 112°; and Bow at 121°; but Briſtol china ſhewed no appearance of vitrification at 135°. The common ſort of Chineſe porcelain does not perfectly vitrify by any fire I could produce; but began to ſoften about 120°, and at 156° became ſo ſoft as to ſink down, and apply itſelf cloſe upon a very irregular ſurface underneath. The true ſtone Nankeen, by this ſtrong heat, does not ſoften in the leaſt; nor does it even acquire a porcelain texture, the unglazed parts continuing in ſuch a ſtate as to imbibe water and ſtick to the tongue. The Dreſden porcelain is more refractory than the common Chineſe, but not equally ſo with the ſtone Nankeen. The cream-coloured or Queen's ware bears the ſame heat as the Dreſden, and the body is as little affected by this intenſe degree of fire.

Mr. POTT ſays, that to melt a mixture of chalk and clay in certain proportions, which proportions appear from his tables to be equal parts, is "among the maſter-pieces of art." This mixture melts into a perfect glaſs at 123° degrees of this thermometer.

The whole of Mr. POTT's or any other experiments may, by repeating and accompanying them with theſe thermometric pieces, have their reſpective degrees of heat aſcertained, and thereby be rendered more intelligible, and uſeful, to the reader, the experimenter, and the working artiſt.

I flatter myſelf that a field is thus opened for a new kind of thermometrical inquiries; and that we ſhall obtain clearer ideas with regard to the differences of the degrees of ſtrong fire, and their correſponding effects upon natural and artificial bodies; thoſe degrees being now rendered accurately meaſurable, and comparable with each other, equally with the lower degrees of heat which are the province of the common mercurial thermometer.

APPENDIX.

ANALYSIS OF THE CLAY OF WHICH THE THERMOMETRIC PIECES ARE FORMED.

THIS clay makes no efferveſcence with acids. Diluted nitrous and marine acids being boiled upon it, and afterwards ſaturated with fixed alkali, no precipitation or turbidneſs appeared. It therefore contains no calcareous earth, as that earth would have been diſſolved by the acids, and precipitated from them by the alkali.

Calcined with powdered charcoal, it contracted no ſulphureous ſmell, and the acids had no more action upon it than before. It therefore contains no gypſeous matter, or combination of calcareous earth with vitriolic acid; as that acid would have formed ſulphur with the inflammable principle of the charcoal, and left the calcareous earth pure, or in a ſtate of ſolubility by acids.

Some of the clay was calcined with an equal weight of ſalt of tartar, which, for the greater certainty in regard to its purity, had been run *per deliquium*, and afterwards evaporated to dryneſs. The calcined mixture was boiled in water, the filtered liquor ſlowly evaporated, and ſuffered to cool at intervals. No cryſtallization was formed: the dry ſalt appeared merely alkaline as at firſt, and deliquiated in the air; a further proof that this clay contains no gypſeous matter; for the vitriolic acid would have been abſorbed by the alkali, and formed vitriolated tartar, a ſalt which neither liquefies in the air, nor diſſolves eaſily in water, and which therefore would have cryſtallized long before the alkali became dry, or remained after its deliquiation.

A twentieth part of gypſum, ground with clay, was very diſtinguiſhable by both the foregoing proceſſes; producing a ſulphureous ſmell, and calcareous earth by calcination with charcoal powder; and cryſtals of vitriolated tartar by calcination with the ſame alkaline ſalt.

To ſeparate the pure argillaceous part, or that matter which in all clays forms alum with the vitriolic acid, 240 grains of this clay were thoroughly moiſtened with oil of vitriol, boiled to dryneſs, and at laſt made nearly red-hot. The mixture was then boiled in water; the earth which remained undiſſolved was treated again in the ſame manner with vitriolic acid, and this operation repeated five or ſix times. The clay was diminiſhed in the firſt operation about 70 grains; but leſs and leſs in the ſucceeding ones, and in the laſt ſcarcely two grains. The filtered liquors yielded cryſtals of true alum; but its quantity was not examined, as the produce of alum from aluminous earth is already ſufficiently known, and the quantity of aluminous earth itſelf, or its proportion to the indiſſoluble earth, was here the object. From the 240 grains of clay there remained in one experiment 98, and in another 95 grains of indiſſoluble earth; ſo that five parts of this clay conſiſt of three parts of pure argillaceous or alum earth, and two parts of an earth of a different kind.

With reſpect to the nature of this laſt earth, it is eaſier to determine negatively what it is not, than poſitively what it is; but aſcertaining the former will be a great ſtep towards the diſcovery of the latter.

That

That it is not calcareous, gypſeous, or argillaceous, is manifeſt from the experiments.—It is not jaſper; as this conſiſts, in great part, of argillaceous earth, which would have been extracted by the vitriolic acid.—It is not fluor; as this, by the ſame acid, would have been decompoſed, its own acid expelled, and a gypſeous earth left.—It is not of the micaceous kind; as the peculiar aſpect of theſe earths would readily betray them to the eye.—It is not granite; for ſtrong fire, which granite melts in, has no effect upon this.

Nor is there any known kind of earth to which it is in any degree ſimilar, except thoſe of the ſiliceous order; and with theſe it perfectly agrees in all the properties, I am acquainted with, that they poſſeſs in a ſtate of powder.

It does not vitrify or ſoften with pure clay, in the ſtrongeſt fire I have been able to produce. Nor is it diſpoſed to melt with the matter of Heſſian crucibles; for a little of it rubbed on the inſide of a crucible, and urged with ſtrong fire, continued white, powdery, and unaltered. Thirty grains of this earth were mixed with an equal weight of dry foſſil alkali, and the ſame quantity of a fine white quartzy ſand was mixed with the ſame proportion of the ſame alkali: the two mixtures were put into two ſmall crucibles, which were ſurrounded with ſand in a larger one, that both might be expoſed to an equal heat. They both began to melt at the ſame time; and at about 80° of the thermometer they had formed perfect tranſparent glaſſes.

Though theſe properties may not, perhaps, be thought ſufficient of themſelves, for determining with certainty that this ſubſtance is of the ſiliceous kind; yet, when joined to the negative proofs, of its not belonging to any other known order of earthy bodies, they afford the fulleſt evidence which the nature of the ſubject can admit of, that the indiſſoluble part of this clay is truly ſiliceous; and conſequently that the clay conſiſts of two parts of pure ſiliceous earth, to three parts of pure argillaceous or aluminous earth.